

**WAFER HEATING APPARATUS HAVING FLUID HEAT TRANSFER MEDIUM  
AND METHOD OF HEATING A WAFER USING THE SAME**

**BACKGROUND OF THE INVENTION**

1. Field of the Invention

5 The present invention relates to a method of and apparatus for heating a wafer in a process of fabricating semiconductor devices.

2. Description of the Related Art

10 The fabricating of semiconductor devices typically includes a photolithography process in which a wafer is coated with liquid photoresist (PR) to form a PR film, the PR film is patterned by being exposed to light produced by an optical source and passed through a mask or reticle, the pattern is developed, and the wafer is heated to a predetermined temperature several times throughout the course of these steps.

15 Apparatus for performing this photolithography process thus requires a PR coater, an exposure device, a developer, and a baking unit. The current trend in such technology is the use of a system in which the PR coater, the developer and the baking unit are clustered in one place, whereby the distance required to move the wafer between the devices and hence, the time required to move the wafer therebetween, is minimized. In other words, the clustered system is capable of performing the conventional photolithography process with a high degree of

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efficiency.

The PR coater is typically of a type which performs a spin coating method in which the wafer is rotated at a predetermined speed, and photoresist solution is sprayed onto the rotating wafer. As a result, the photoresist is uniformly spread over the wafer by centrifugal force.

The heating of the wafer during the fabricating of a semiconductor device is generally considered to include four steps. The first step is a pre-baking step of heating a wafer at a predetermined temperature to evaporate organic materials or foreign materials from the surface of the wafer. The second step is a soft-baking step of heating the wafer just after the wafer is coated with the photoresist to dry the photoresist and strongly attach the film of photoresist to the surface of the wafer. The third step is a post-exposure-baking (PEB) step of heating the photoresist which has been exposed. The fourth step is a hard-baking step of heating a wafer just after the photoresist film has been developed so as to strongly attach the resultant photoresist pattern to the wafer surface.

When the exposure device comprises a source of ultra violet (UV) and deep ultra violet (DUV) light, the light diffracts and produces interference according to the reflectivity and refractive index of the substrate, such as a wafer, and the optical absorptivity of the photoresist film, irradiated with the light. The phenomena of interference, in turn, causes the profile of the pattern of the photoresist to be abnormal, and the critical dimension of the pattern to be non-uniform. The PEB step is

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performed to compensate for these problems. In the PEB step, the exposed photoresist film is heated at a predetermined temperature to rearrange the resins which were optically decomposed due to thermal diffusion, thereby cleaning the cross section of a profile of the exposed pattern. When the exposure light is a DUV light, a chemically-amplified resist is used as the photoresist. A portion of the chemically-amplified resist, which is exposed by thermal treatment, changes into an acid which is soluble in a developing solution. Also, the alteration of the chemically-amplified resist occurs due to a chain reaction, so that the balance of heat applied to the entire wafer in the PEB step has the greatest effect on the uniformity of the critical dimension of the photoresist pattern.

Hence, a uniform heating of the entire surface of the wafer is very important to increasing the yield. A heating device of a conventional baking unit, as shown in FIG. 1, includes a lower plate 2 in which an electrical heat source, that is, a heater 21, is installed. The heater 21 is situated just below the lower surface of an upper plate 1 on which a wafer 100 is supported. Referring to FIGS. 2 and 3, a spiral groove 22 is formed in the upper surface of the lower plate 2, and the heater 21 is seated in the groove 22. In this structure, heat generated by the heater 21 is transferred from the lower plate 2 to the upper plate 1 to heat the wafer 100 on the upper plate 1. Also, the power of the heater 21 is feedback-controlled, by detecting the temperature of the upper plate 1 using a temperature sensor (not shown) installed on the lower plate 2, so that the temperature is kept within a predetermined range. In the conventional

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heating device, heat is conducted via the bodies of the upper and lower plates 1 and 2. Consequently, an uneven thermal distribution occurs at the surface of the upper plate 1.

FIG. 4 is a temperature distribution diagram illustrating the temperature at the surface of a wafer heated by the conventional heating device, wherein the temperature difference between adjacent isotherms is  $0.02^{\circ}$ . As shown in FIG. 4, the temperature distribution is irregular and abnormally distorted, and the difference in temperature between the coolest and warmest regions is about  $1.76^{\circ}$ . In this figure, bold isotherm A crossing the center of a wafer indicates a temperature of  $145.31^{\circ}$ , isotherm B indicates a temperature of  $146.28^{\circ}$ , and isotherm C indicates a temperature of  $144.32^{\circ}$ . As can be seen from this temperature distribution, the temperature of the surface of the wafer gradually increases on one side of the bold isotherm A and reaches  $146.28^{\circ}$  at one peripheral portion of the wafer, and gradually decreases on the other side of the bold isotherm A and reaches  $144.32^{\circ}$  at another peripheral portion of the wafer. This irregular temperature distribution and wide temperature difference greatly affects the yield as described above. Therefore, the temperature distribution produced by heating the wafer must be improved by all means.

FIG. 5 is a temperature-time graph showing variations in temperature of regions of a wafer while the wafer is being heated by the conventional heating apparatus, and FIG. 6 shows the locations at which the temperature of the wafer surface are measured. These locations include the center of the wafer surface, and various points

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on two circles which are concentric with the center of the wafer surface.

Referring to the variations in temperature obtained by taking temperature readings at the above-described points, as shown in FIG. 5, the temperature differs greatly amongst the measuring points at any given time. Moreover, after a  
5 predetermined time passes, the temperature drops sharply ( zone D in the figure). Such great differences in temperature imparts a serious thermal shock not only to the wafer but also to the photoresist film formed on the wafer. Such a thermal shock adversely affects the physicochemical property of the photoresist film.

Therefore, the conventional heating apparatus described above impedes the  
10 success of the photolithography process in forming a photoresist having a normal profile and uniform critical dimension on a wafer. Thus, the conventional heating apparatus is an impediment to enhancing the yield. In particular, as the design rule of patterns get finer and finer to, for example,  $0.25\mu\text{m}$ ,  $0.18\mu\text{m}$ , and  $0.15\mu\text{m}$  to meet the demand for increases in the level of integration of the circuits, the above-described  
15 problem becomes more and more serious.

#### SUMMARY OF THE INVENTION

Accordingly, an object of the present invention is to provide a method of and apparatus for uniformly heating a wafer in order to prevent a thermal shock from being applied to the wafer and to a photoresist film formed on the wafer.

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Another object of the present invention is to provide a method of and apparatus for heating a wafer in such a way that only a small deviation in temperature exists over the surface of the wafer.

To achieve these objects, the present invention provides a method of heating a  
5 wafer including steps of: generating heat to be supplied to a wafer; transmitting the heat to a fluid heat transfer medium whose liquid component is changed into a vapor; transferring heat from the vapor of the fluid heat transfer medium to a solid heat medium, whereby the loss of heat by the vapor condenses the vapor back into a liquid; and supporting the wafer with the solid heat transfer medium so that the wafer is  
10 heated using the heat derived from the vapor of the fluid heat transfer medium.

The solid heat transfer medium can be substantially only heated by the heat of the vapor of the fluid heat transfer medium, i.e., by radiant heat, by minimizing the thermally conductive structure extending from the source of heat to the solid heat transfer medium.

15 The present invention also achieves these objects by providing wafer heating apparatus comprising: a heat source; a solid heat transfer medium which is to support the wafer; and a fluid heat transfer medium contained in a closed space located between the solid heat transfer medium and the heat source.

20 A plurality of partitions may be interposed between the solid heat transfer medium and the heat source to divide the enclosed space into a plurality of discrete areas each containing some of the fluid heat transfer medium. The partitions can be

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constituted by a lattice for ease of installation.

Furthermore, a porous refractory body may be provided in the enclosed space with the heat transfer medium being contained in the cavities of the porous refractory body. The porous body can consist of a single unitary body interposed between the solid heat transfer medium and the heat source. Alternatively, the porous refractory body may comprise several sections disposed in contact with the heat source within areas of the enclosed space partitioned from one another, respectively.

Still further, the fluid heat transfer medium can be provided in at least one groove formed by the lower surface of the solid heat transfer medium and/or an upper surface of the heat source. The at least one groove may consist of a single groove having the shape of a closed loop, or may comprise a plurality of independent grooves closed off from one another.

A coronary body, containing the fluid heat transfer medium, may be provided within the groove. Preferably, the coronary body has a plurality of internal heat radiating fins which contact the fluid heat transfer medium.

#### BRIEF DESCRIPTION OF THE DRAWINGS

The above and other objects, features and advantages of the present invention will become more apparent from the following detailed description of preferred embodiments thereof made with reference to the attached drawings, of which:

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FIG. 1 is a schematic cross-sectional view of wafer heating apparatus of a conventional baking unit;

FIG. 2 is a plan view of the heat source of the conventional wafer heating apparatus;

5        FIG. 3 is an enlarged view of part of the heat source of the conventional wafer heating apparatus;

FIG. 4 is a temperature distribution diagram of a wafer surface heated by the conventional wafer heating apparatus;

FIG. 5 is a graph showing variations in the temperatures of regions of a wafer with respect to time while the wafer is being heated by the conventional wafer heating apparatus;

FIG. 6 shows the locations where the surface temperature of a wafer heated by the conventional wafer heating apparatus were measured to yield the temperature distribution diagram shown in FIG. 5;

5        FIG. 7 is a schematic side view of a first embodiment of wafer heating apparatus according to the present invention;

FIG. 8 is a schematic cross-sectional view of the heat source of the wafer heating apparatus according to the present invention;

FIG. 9 is an enlarged view of part of the heat source;

20        FIG. 10 is a schematic side view of a second embodiment of wafer heating apparatus according to the present invention;



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FIG. 11A is a schematic perspective view of a lattice which may be employed in the second embodiment of the wafer heating apparatus according to the present invention;

FIG. 11B is a schematic perspective view of another form of the lattice suitable for use in the second embodiment of the wafer heating apparatus according to the present invention;

FIG. 12 is a schematic side view of a third embodiment of wafer heating apparatus according to the present invention;

FIG. 13 is a schematic side view of a fourth embodiment of wafer heating apparatus according to the present invention;

FIG. 14 is a schematic cross-sectional view of a fifth embodiment of wafer heating apparatus according to the present invention;

FIG. 15 is a bottom view of a solid heating medium which may be employed in the fifth embodiment of the wafer heating apparatus according to the present invention;

FIG. 16 is a schematic cross-sectional view of a sixth embodiment of wafer heating apparatus according to the present invention;

FIG. 17 is a cross-sectional view of part of a seventh embodiment of wafer heating apparatus according to the present invention;

FIG. 18 is a schematic cross-sectional view of a coronary body which can be employed in the seventh embodiment of the wafer heating apparatus according to the

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present invention;

FIG. 19 is a surface temperature distribution diagram of a wafer heated by wafer heating apparatus according to the present invention;

FIG. 20 is a surface temperature distribution diagram of another wafer heated  
5 by wafer heating apparatus according to the present invention; and

FIG. 21 is a graph showing variations in the temperatures of regions of a wafer with respect to time while the wafer is being heated by the wafer heating apparatus according to the present invention.

#### DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

Referring first to FIG. 7, wafer heating apparatus according to the present  
10 invention includes a solid heat transfer medium 10 which supports a wafer 100 in direct contact therewith, a heat source 20, and a fluid heat transfer medium 30 interposed between the solid medium 10 and heat source 20. The state of the fluid medium 30 is changeable between a vapor and liquid state by heating the medium  
15 with the heat source 20 and allowing the medium to cool. Here, the arrows in the solid heat transfer medium 10 and the heat source 20 indicate the direction of movement of heat, and the arrows in the fluid heat transfer medium 30 indicate the direction of movement of the fluid medium. A portion of the fluid heat transfer medium 30 adjacent the solid heat transfer medium 10 is in a vapor state, and a portion of the fluid  
20 heat transfer medium 30 adjacent the heat source 20 is in a liquid state. The fluid heat

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transfer medium 30 absorbs heat from the heat source 20, and moves toward the solid heat transfer medium 10 while being vaporized. When the vapor of the fluid heat transfer medium 30 contacts the solid heat transfer medium 10, it transmits heat to the solid heat transfer medium 10. The transfer of heat cools the vapor, causing it to  
5 condense, whereby the resultant liquid moves toward the heat source 20. The absorption of heat from the heat source 20 by the fluid heat transfer medium 30, and the transfer of heat to the solid medium 10 is a continuous cycle, during which a phase change of the fluid heat transfer medium 30 occurs continuously. A phase change of the fluid heat transfer medium occurs according to the critical temperature and  
10 pressure of the fluid medium.

The cycle of heat transfer occurs within a closed space according to the present invention, and is very fast as compared to the cycle of heat transfer which occurs in the conventional heating apparatus. The fluid medium of the present invention transfers the heat to the surface of the solid heat transfer medium 10 rapidly and  
5 evenly, whereupon the heat is uniformly transferred to the wafer 100 supported on the solid medium 10. Therefore, the surface of the wafer 100 is rapidly and uniformly heated by the heat evenly distributed throughout the solid heat transfer medium 10.

As shown in FIGS. 8 and 9, the heat source 20 includes a heater 203 comprising an electrical heating coil, and upper and lower heater blocks 201 and 202  
20 which contain the heater 203. More specifically, the heater 203 is contained within a groove 204 formed in the lower surface of the upper heater block 201 or in the upper

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surface of the lower heater block 202.

A space in which the fluid heat transfer medium 30 is contained can be partitioned into a plurality of areas, as shown in FIG. 10.

Referring now to FIG. 10, a plurality of partitions 301 are installed between the  
5 solid heat transfer medium 10 and the heat source 20. Accordingly, the fluid heat transfer medium 30 exists within areas partitioned by the plurality of partitions 301, and a phase change occurs in independent spaces delimited by the plurality of partitions 301.

The partitions 301 can constitute a lattice 302 having rectangular or  
10 honeycomb-shaped units, as shown in FIGS. 11A and 11B. Preferably, the cross sections of the units of the lattice 302 are designed so that the units will act as capillary tubes for the fluid heat transfer medium 30.

Referring to FIG. 12, a refractory porous body 303 having discrete sections is preferably provided within the units of the lattice 302 in contact with the heat source  
20. The fluid heat transfer medium 30 thus fills the cavities of the porous body 303. The fluid heat transfer medium 30 thus contained in the cavities of the refractory porous body 303 will be rapidly heated and evaporated. Also, the cavities act as capillary tubes which promote the mobility of the fluid heat transfer medium 30.

Alternatively, as shown in FIG. 13, the refractory porous body 303 can be a  
20 single body interposed between the solid heat transfer medium 10 and the heat source 20. In this case, the refractory porous body 303 closely adheres to the inner surfaces

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of both the heat source 20 and the solid heat transfer medium 10, or to the inner surface of either the heat source 20 or the solid heat medium 10.

FIGS. 14 and 15 show another embodiment of the heating apparatus according to the present invention. In this embodiment, the solid heat medium 10 adheres to the heat source 20, and a groove 101 containing the fluid heat transfer medium 30 is formed at the interface between the solid heat transfer medium 10 and the heat source 20.

In particular, the groove 101 is formed in the bottom surface of the solid heat transfer medium 10, but can be formed in the surface of the heat source 20 in some circumstances. The groove 101 forms a closed loop at the interface between the solid heat transfer medium 10 and the heat source 20, through which loop the fluid heat transfer medium 30 can circulate. The end 101a of the groove 101 is open at the side surface of the solid heat transfer medium 10 or the heat source 20 so that the fluid heat transfer medium 30 can be placed in the groove 101. A plug 10a closes the open end 101a of the groove 101.

In this structure, while the fluid heat transfer medium 30 circulates along the groove 101, the phase of the fluid heat transfer medium 30 is changed due to heat absorption and heat transmission as described above. The loop of fluid heat transfer medium 30 leaves portions where the solid heat transfer medium 10 and the heat source 20 directly contact each other. Accordingly, heat is also transmitted from the heat source 20 to the solid heat transfer medium 10 via the contacting portions of the

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solid heat transfer medium 10 and the heat source 20.

However, heat transfer via the fluid medium 30 circulating in the groove 101 occurs at a faster rate than the direct heat transfer via the contacting portions of the solid medium 10 and the heat source 20.

5           Meanwhile, the groove 101 can have a shape other than that of a single closed loop. That is, a plurality of grooves 101 can be formed in the lower surface of the solid heat transfer medium 10 or in the surface of the heat source 20. The plurality of grooves 101 are laid out at regular intervals across the interface between the solid heat transfer medium 10 and the heat source 20. The independent grooves form discrete closed spaces in which the phase of the fluid heat transfer medium 30 is changed.

FIG. 16 shows an embodiment in which the grooves 101 form a plurality of independent spaces as described above. Referring now to FIG. 16, a plurality of grooves 101 are formed in the upper surface of the heat source 20. Walls 104 which isolate the grooves 101 from each other have triangular profiles. A vertex of each triangular wall 104 contacts the lower surface of the solid heat transfer medium 10. This minimal contact between the wall 104 and the solid heat transfer medium 10 minimizes heat transfer from the former to the latter.

FIG. 17 shows an embodiment in which a coronary (tubular) body 102 extends in the groove 101. The fluid heat transfer medium is contained in the coronary body 102. In this structure, the groove 101 extends in a closed loop at the interface between

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the solid heat transfer medium 10 and the heat source 20.

Referring to FIG. 18, the coronary body 102 includes fins 103 which contact the fluid heat transfer medium 30 in order to promote the phase change of the fluid heat transfer medium 30. The fins 103 extend axially in the direction of movement of the fluid heat transfer medium 30 along the coronary body 102. As an alternative to the fins 103, a porous layer of a predetermined thickness can be formed on the inner wall of the coronary body 102.

According to the present invention as described above, the fluid heat transfer medium must be one whose phase can be changed between vapor and liquid phases within a predetermined range of temperatures targeted for heating a wafer during a semiconductor manufacturing process, e.g., in the photolithography process. When considering that the targeted temperature to which a wafer is heated is between 200°C and 300°C, the fluid heat medium can be, but it is not limited to, water, ethanol, methanol, acetone, ammonia, or Freon.

FIGS. 19 and 20 are isotherm diagrams showing the distribution of surface temperatures of a wafer heated by heating apparatus according to the present invention. As can be seen from these figures, the isotherms are annular, the center of the wafer has the highest temperature, and the temperature decreases in a uniform pattern from the center toward the periphery of the wafer. It is also clear that the isotherm distribution shown in FIG. 20 is preferable to that shown in FIG. 19.

In the isotherm diagram of FIG. 19, the difference between the highest and lowest temperatures is  $0.73^{\circ}\text{C}$ , the bold isotherms indicate a temperature of  $155.63^{\circ}\text{C}$ , the temperature of the center of the wafer is  $156.00^{\circ}\text{C}$ , and the lowest temperature of the wafer periphery is  $155.26^{\circ}\text{C}$ . In the isotherm diagram of FIG. 20, the difference between the highest and lowest temperatures is  $0.72^{\circ}\text{C}$ , the bold isotherm indicates a temperature of  $155.63^{\circ}\text{C}$ , the temperature of the center of the wafer is  $155.960^{\circ}\text{C}$ , and the lowest temperature of the wafer periphery is  $155.32^{\circ}\text{C}$ .

As can be seen from FIGS. 19 and 20, the temperature of a wafer has an even distribution over the surface of the wafer, and particularly, the deviations between the highest and lowest temperatures of  $0.73^{\circ}\text{C}$  and  $0.72^{\circ}\text{C}$  are excellent results which cannot be obtained by the conventional wafer heating apparatus.

FIG. 21 is a graph showing temperature-time variations obtained from a plurality of measuring points while a wafer was heated by heating apparatus according to the present invention. As shown in FIG. 21, after heating starts, the temperature increases sharply, and thermal vibration, that is, a temperature variation with respect to the lapse of time, is gentle. In particular, a sudden drop in temperature, as occurs when using conventional heating apparatus, does not occur when practicing the present invention. This tiny temperature variation over the wafer, and the small thermal vibration show that a very weak thermal shock is applied to the wafer and to the photoresist film formed on the wafer.



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According to the present invention as described above, stable heating of a wafer with a very small temperature deviation greatly reduces the intensity of a thermal shock on the wafer and a photoresist film formed on the wafer, and particularly, the wafer can be heated with a regular and uniform temperature distribution. Accordingly, the present invention allows finer patterns to be formed successfully even under a design rule in which the critical dimension is  $0.25\mu\text{m}$ ,  $0.18\mu$ , or  $0.15\mu\text{m}$ , with an increase in the level of the integration of circuits, thus greatly increasing the yield.

Although the invention has been described with reference to particular embodiments thereof, it will be apparent to those of ordinary skill in the art that modifications of the described embodiments may be made without departing from the spirit and scope of the invention as defined by the appended claims.